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ABSTRACT

This publication is an extended essay by the president of Indiana University on the impact of the sciences at Indiana University (IU) and beyond. In several sections it addresses the nature of discovery, science and society, the research university, and learning and teaching. The essay often refers to past and present IU faculty in astronomy, biology, chemistry, computer science, geology, mathematics, and physics. The section on discovery explores the importance of careful study and work to lay the foundations for discovery and creative insight. In the section on science and society, the importance of research in areas of no immediate commercial benefit is stressed. In discussing the research university, the essay notes the key role such institutions play and argues for a commitment to the process of knowledge rather than its products. In the section on teaching and learning, the thoughts of some IU teachers are shared and an argument is made regarding the great teachers who, it is noted, are nearly always great learners dedicated to increasing human knowledge. A final section is on the future and looks at the financial challenges to institutions like IU, the importance of combining public and private funding, of increasing undergraduate opportunities to do research, and of participation in efforts to support and improve science education from elementary grades through higher education. (JB)

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Our University in the State: The Sciences

Thomas Ehrlich
President
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Our UNIVERSITY in the STATE: The Sciences

The essential character of the university is freedom of learning, the freedom of the student to pursue studies to the limit of the known, the freedom of encouragement to invade the realm of the unknown. The university should be the great refuge-hut on the ultimate boundaries of knowledge, from which, daily and weekly, adventurous bands set out on voyages of discovery.

David Starr Jordan
President of Indiana
University,
1885-1891

There is an intellectual magnetism in people who spend their lives searching for new knowledge, and I think that magnetism comes through in the classroom in ways that are crucial to the learning process.

George Walker
Vice President for Research

The Refuge-Hut

One recent evening, I rediscovered a volume of essays by David Starr Jordan, given to me some years ago by a friend who knows that Jordan is one of my heroes. A professor of biology and world-renowned expert on fishes, David Starr Jordan was named president of Indiana University in 1885 at the age of 33—the youngest person ever to become president of IU, and the first scientist.

Jordan immediately launched pioneering innovations in the curriculum; hired brilliant young faculty; added new departments, nearly doubling their number; and encouraged scientific research—an unaccustomed activity at universities in those days. He also went right on teaching. During one semester, in the spring of 1888, he taught mineralogy, vertebrate zoology, ichthyology, Norwegian, and the first course in the world—so he claimed—on Darwin's theory of evolution, a highly unpopular theory at the time.

My volume of Jordan's essays, *Care and Culture of Men*, includes "Science and the Colleges," written in 1892. Jordan described the transition then occurring in the role of science in American higher education—a transition in which he was a prime mover:

I remember very clearly that twenty years ago, when I had prepared myself for the two professions of naturalist and college professor, I found that these professions were in no way related.

The college course in those days led to no free air. Its essentials were the grammar of dead languages, and the memorized results of the applications of logic to number and space. . . . The investigator had no part in the college system, or if on sufferance he found a place, his time was devoted to anything else rather than to the promotion of science. Everywhere in Europe and America were men who were devoting their lives eagerly to scientific research; but, in nine cases out of ten, these men were outside of the colleges.

Jordan told of the gradual "relaxation of the chains of the curriculum," allowing for the development of scientific courses, and the admission by colleges, "slowly and grudgingly," that there was value in the study of science. He saw clearly the directions that American colleges and universities needed to take in science education and the advancement of scientific knowledge. His vision of a century ago predicted the shape of things to come:

The University should be the great refuge-hut on the ultimate boundaries of knowledge, from which, daily and weekly, adventurous bands set out on voyages of discovery. . . . [T]he same house of refuge and supply will serve for a thousand

Jordan saw clearly the directions that American colleges and universities needed to take in science education and the advancement of scientific knowledge.

different exploring parties, moving out in every direction into the infinite ocean. Some day it will be felt as a loss and a crime if any one who could be an explorer is forced to become anything else. And even then, after countless ages of education and scientific progress, the true university will still stand on the boundaries, its walls still washed by the same unending sea, the boundless ocean of possible human knowledge.

David Starr Jordan had only six years as president of IU—in 1891 he was lured to California to become the first president of Stanford University—but he made the most of his time. We owe the character of the University today in great measure to the directions he set.

As a refuge-hut, Indiana University has supported extraordinary scientific explorers, past and present.

As a refuge-hut, Indiana University has supported extraordinary scientific explorers, past and present. Many of today's explorers, whose work is reflected in the pages that follow, have been my tutors in the last six years, introducing me to a dazzling array of new knowledge.

Other explorers of earlier years are legends of our history—among them four Nobel Prize winners, whose careers are connected to IU and to each other. The first was Hermann Muller, a geneticist who received the Nobel Prize in medicine and physiology in 1946, just a year after joining the IU faculty. Salvador Luria, honored with the Nobel Prize in medicine in 1969, began his teaching career at IU in the 1940s as a young professor of biology. Renato Dulbecco, who received the Nobel Prize in medicine in 1975, made Indiana University his first academic home when he emigrated from Italy, serving as a research associate in biology here from 1947 to 1949.

The fourth Nobel Prize winner, James Watson, earned worldwide renown for his part in the discovery of the structure of DNA, the key to the modern revolution in molecular biology. He received the Nobel Prize in medicine in 1962 with Francis Crick and Maurice Wilkins. Watson, who was 34 when he was awarded the Nobel Prize, earned his doctorate in biology at Indiana University in 1950, writing his doctoral thesis at the age of 22.

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While James Watson was here he knew Renato Dulbecco, and studied under Hermann Muller and Salvador Luria. He also was a student of Tracy Sonneborn, chair of the division of biological sciences and a member of the National Academy of Sciences. Dr. Sonneborn used to relate how Watson would sit in his class, not taking a single note. "Mr. Watson never took notes in lectures," Dr. Sonneborn said, "except references to publications. Then Watson would go to the library and read all the available material on the subject at hand."

These illustrious biological scientists—all here together at the same time—were brought to IU by Dean of the Graduate School Fernandus Payne and President Herman B Wells, whose genius in attracting brilliant minds to Indiana University knew no bounds.

The 1940s was a decade of flourishing new endeavors in science at IU that opened the way for today's achievements. The Indiana University Cyclotron Facility got its start then. The original cyclotron built here in 1941 was one of the first in the world. Research in accelerator-based nuclear physics at Indiana University spans nearly the entire history of the field. Today more than 200 physicists from around the world come to the facility each year to carry out research projects that, because of the specialized range of our cyclotron, can be done only at IU.

The original cyclotron built here in 1941 was one of the first in the world.

During the 1950s, IU chemists Harry Day, Joseph Muhler, and William Nebergall discovered the extraordinary effectiveness of stannous fluoride—a previously little-known compound—in preventing tooth decay. The three researchers worked out a process for incorporating stannous fluoride in toothpaste, revolutionizing preventive dentistry and improving the dental health of millions around the world. Ninety percent of Americans now use a fluoridated toothpaste, and more than 50 percent have fluoride in their water.

Great events in the making are often perceived differently by persons close to them than by others more removed. A colleague on the faculty, himself an eminent chemist, had an office near the laboratory and witnessed the stannous fluoride research in progress. "What I remember most," he told me recently, "is all the rats with excellent teeth."

During the 1950s, IU chemists Harry Day, Joseph Muhler, and William Nebergall discovered the extraordinary effectiveness of stannous fluoride—a previously little-known compound—in preventing tooth decay.

Among many achievements in the Department of Astronomy, IU faculty members—aided by the facilities of our Goethe Link Observatory—have discovered more than 100 minor planets. A minor planet discovered in 1973, by a research team headed by former chair of astronomy Frank Edmondson, was named after Herman B Wells. When the name was confirmed by the International Astronomical Union, Herman Wells's longtime friend, Eli Lilly, was inspired to write the following tribute:

How appropriate it befells
That the planet is named Herman Wells.
Against all odds
He now orbits with the gods.
So let's turn out and ring all the bells.

Herman B Wells presided over Indiana University during the quarter century—from 1937 to 1962—that saw American universities move vigorously into the role David Starr Jordan had predicted for them in the advancement of science. With his extraordinary capacity to foresee opportunities for greatness, Herman Wells ensured that the splendid scientists and scholars he attracted here from around the world would find at Indiana University an environment that nurtured achievement. In his autobiography, *Being Lucky*, he expresses his vision of the central place of research in the university:

The search for answers is common to all human beings. From babyhood onward, we seek to learn the what, where, why, and when of much that is around us. Research is the highly

specialized, sophisticated form of that quest. Universities must not only distill to students the answers of the past and present, but even more importantly universities must abet the new, wider, and deeper searches that will advance the knowledge of ourselves and the world around us.

Often it may be the insight of a colleague working in a quite different field that provides the unexpected link between ideas to spark new understanding.

Today IU's eight campuses are home to more than 100 research centers and institutes, spanning the physical and biological sciences, the humanities, the social sciences, and the professions. Many of these centers are multidisciplinary, designed to promote interactions across several fields. One example is the Center for Research on Concepts and Cognition at Bloomington. Headed by Pulitzer Prize–winning author and Professor of Cognitive Science and of Computer Science Douglas Hofstadter, the Center brings together faculty and students from anthropology, computer science, education, linguistics, mathematics, philosophy, physiology, psychology, sociology, and speech and hearing sciences—all explorers in the field of cognitive science, the study of how we know what we know.

These multidisciplinary research centers underscore that the growth of understanding comes not from isolated bits of information, but from the connections we make between them. The creative search for those connections, for the relationships among the parts and the whole, is the driving force that advances knowledge. Often it may be the insight of a colleague working in a quite different field that provides the unexpected link between ideas to spark new understanding.

Science as we know it today is a latecomer. In Galileo's time, the term "natural philosophy" was given to studies that were equivalent to all the physical sciences of today—the whole range of the natural world. In the great universities of the Middle Ages, at Paris and Bologna and other European intellectual centers, scholars devoted themselves to the pursuit of a universal body of learning that they believed would encompass all known reality and human experience. In that time one could call oneself a "natural philosopher," someone whose field of study was the whole natural world.

But in science, as in other areas of human inquiry, progress came in two directions. As knowledge expanded, it enforced specializations. The same forces also led to the discovery of new connections among specialties, and these connections became in themselves whole new fields.

A research university must allow for the creative development of new fields—and encourage the interactions across fields that lead to that essential creativity.

This process continues to produce new fields today. Cognitive science is one example. Another is the joining of engineering, biology, physics, and chemistry to create the emerging field of biotechnology. A research university must allow for the creative development of new fields—and encourage the interactions across fields that lead to that essential creativity.

Amid the news, bad and good, from around the world last summer was a surprising item—surprising, anyway, for the

front-page attention and the popular interest it received: A young English mathematician named Andrew Wiles had solved a 350-year-old mathematical puzzle called "Fermat's Last Theorem." Pierre de Fermat, who laid the foundation for probability theory in the 17th century, claimed that although there are solutions for $A^2 + B^2 = C^2$ ($3^2 + 4^2 = 5^2$ is one), no solutions exist, using whole numbers, for powers above the square. Thus $A^3 + B^3 = C^3$ will not work, no matter what whole numbers you use, nor will $A^4 + B^4 = C^4$, and so forth *ad infinitem*. It took Dr. Wiles 200 pages to explicate his proof that Fermat was right.

What is remarkable is that not just mathematicians, but lay people as well are intrigued by Dr. Wiles's achievement—and by Fermat's puzzle. Science, even esoteric science, has us in its thrall. We live in a scientific world. Our world views, our ideas about ourselves and the universe, are tinctured by the revolutionary discoveries of the 20th century—and by the heady thought that humankind has the power to make those discoveries, to see with the mind's eye into deepest space and remotest time.

Experimental mathematics and computer modeling are key factors in the rapid advance of scientific knowledge. They enable researchers to step into the interior of stars, to stand by at the birth of the universe, and to boldly go to other impossible places. But perhaps most compelling and most profound, for scientists and nonscientists alike, is the recognition that the hidden laws of the universe are rational laws, accessible to our understanding through the logic of mathematics—and that our brains, capable of that logic, are therefore structured to understand the universe.

The space we live in, as we perceive it through the proliferating lenses of science, grows with our ability to use those lenses. We are no longer just looking up at the night sky, but now outward from star to galaxy to the massed dark matter of the outer reaches. We are no longer just looking inward at the atom, but deeper, from neutron to quark to the particle of infinitesimal duration that carries the nuclear force, holding all together. And what is more, these disparate dimensions of vastness and minuteness possess startling likenesses: As the great astronomer Sir James Jeans put it, "In a sense the secret structure of the atom is written across the heavens in the diameters of the stars."

These new visions tell us that most things are more complex than they appear. Paradoxically, however, they also satisfy in new ways our human longing to find, wherever possible, unity, order, and simplicity. The ideal of unity is as old as science itself. One effort toward that ideal—the goal of a "grand unifying theory," that physicists hope will prove that gravity, electromagnetism, and the strong and weak nuclear forces are but different faces of a single force—is still beyond reach, but tantalizingly nearer.

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The ideal of unity is as old as science itself.

Even the experts find the new ideas hard to wrestle with, when taken to their furthest conclusions.

I am particularly fascinated by recent findings of a new and cosmic unity that appears to emerge from an unlikely source: chaos. Over the past several years, researchers working unknown to each other in biology, economics, mathematics, meteorology, and other fields, using high-powered computers for analysis, began finding unexpected orderly patterns emerging from highly complex, random, and chaotic data. Even more extraordinary, the patterns were the same no matter what the data, from cotton prices to weather patterns, from transition states in liquids and metals to fluctuating animal populations, and more.

The new field of chaos theory that has grown from these discoveries, once the researchers got together, posits that the laws of pattern formation are universal; that diverse complex systems follow the same few simple laws, which in turn generate diverse complex systems—that infinite replications of order and chaos infinitely emerge one from the other.

In other words, no matter what the seeming chaos, if only you step back far enough you will find order. As an administrator, I find that thought comforting. I also find many of the ideas of contemporary science hard to wrestle with, as I think most nonscientists do. But then, we are not alone. Even the experts find the new ideas hard to wrestle with, when taken to their furthest conclusions. Physicist Stephen Hawking writes in *A Brief History of Time*, "The usual approach of science of constructing a mathematical model cannot answer the questions of why there should be a universe for the model to describe. Why does the universe go to all the bother of existing?"

A whole new range of unanswerable, or potentially unanswerable, questions arises from the "advance of scientific theories"—not only *why*, but also *how*.

"Up to now," Hawking continues, "most scientists have been too occupied with the development of new theories that describe *what* the universe is to ask the question *why*. On the other hand, the people whose business it is to ask *why*, the philosophers, have not been able to keep up with the advance of scientific theories."

A whole new range of unanswerable, or potentially unanswerable, questions arises from the "advance of scientific theories"—not only *why*, but also *how*. How, for example, can an infinite number of trajectories fall within a finite space, as appears to happen in certain continuous looping patterns? How can two contradictory statements both be true, as mathematics can show they are? How can the course that an event takes depend on its subsequent measurement, as we find in particle physics? Nobel Prize–winning physicist Richard Feynman once began a lecture by telling the audience, "I think I can safely say that nobody understands quantum mechanics. Do not keep saying to yourself, if you can possibly avoid it, 'But how can it be like that?' . . . Nobody knows how it can be like that." And Sir James Jeans asks at the end of his major work, *Astronomy and Cosmogony*:

What is the meaning, if any there be which is intelligible to us, of the vast accumulations of matter which appear, on our present interpretations of space and time, to have been created only in order that they may destroy themselves? What is the relation of life to the universe, of which, if we are right, it can occupy only so small a corner? What, if any, is our relation to the remote nebulae, for surely there must be some more direct contact than that light can travel between them and us in a hundred million years? Do their colossal uncomprehending masses come nearer to representing the main ultimate reality of the universe, or do we? Are we merely part of the same picture as they, or is it possible that we are part of the artist?

Science cannot answer such questions as these. Yet science does help us to think about them, and to think about them in new ways. At the same time, there may well be no limit to the capacity of science to answer questions of the kinds that it *can* answer, in the course of our voyages on the "boundless ocean of possible human knowledge," in David Starr Jordan's phrase.

This brings me again to the role of science in the university generally, and Indiana University particularly—most especially the role of the scientist as teacher. Research and teaching are too often polarized—at least by those outside the university. But I underscore that students benefit immeasurably from having as role models faculty members whose energy in the classroom derives from their own continual learning in research and scholarship. Much of the science taught today, even in introductory courses, was unknown when I was an undergraduate. Cellular and molecular biology is a prime example. Though the theories I memorized have been replaced, I learned something far more important as a college student—how to learn.

Much of the science taught today, even in introductory courses, was unknown when I was an undergraduate.

Students benefit from having, as guides in the learning process, faculty members who challenge them because they themselves wrestle daily with the questions that science can answer, and those it cannot answer. Time and again it turns out that those we honor for excellence in teaching are the same faculty we honor for excellence in research. The reason is apparent: These teachers bring the spirit of inquiry into the classroom. They are able to infuse their teaching with the frontier spirit of creative discovery precisely because their own work is at the frontier. The eagerness to go beyond certainty into the unknown, the willingness to try and fail and try again, the commitment to advance knowledge and the patience and determination to carry out that commitment for a lifetime—these are values taught more by example than words.

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In his book *The Limits of Science*, biologist Peter Medawar writes, "To be good at science, one must *want* to be—and must feel a first stirring of that sense of disquiet at lack of comprehension that is one of a scientist's few secure distinguishing marks. . . . Good scientists often possess old-fashioned virtues of the kind schoolteachers have always

professed to despair of ever inculcating in us. These are: a sanguine temperament that expects to be able to solve a problem; power of application and the kind of fortitude that keeps scientists erect in the face of much that might otherwise cast them down; and above all, persistence, a refusal bordering on obstinacy to give up and admit defeat." The holders of such qualities as these set inspiring examples from which our students benefit no matter what careers they choose.

I have benefited greatly from my own IU education in the sciences, and many of those who have contributed their thoughts to this essay have been my guides in the process. The essay does not include all aspects of the sciences at Indiana University, or all faculty members who are outstanding in scientific fields—nor does it by any means include all the sciences that are studied and taught at IU. I focus here on astronomy, biology, chemistry, computer science, geology, mathematics, and physics.

I have benefited greatly from my own IU education in the sciences, and many of those who have contributed their thoughts to this essay have been my guides in the process.

The essay is divided under four headings that reflect the impact of the sciences at IU and beyond: discovery, science and society, the research university, and learning and teaching. A final section looks to the future.

Listen now to Indiana University teachers and explorers in the sciences.

Discovery

One of the first books I recall reading that was not written for children is *Microbe Hunters*, by Paul de Kruif, a series of essays about pioneering biologists. I still have my father's 1926 copy. Each chapter describes the work of a different discoverer—Pasteur, Walter Reed, and others. The chapter I remember best is called "Paul Ehrlich: The Magic Bullet." My grandfather claimed a distant relationship to Paul Ehrlich—but much more fascinating to me as a child was the sense of adventure de Kruif conveys as he describes Ehrlich's search for a chemical compound to fight syphilis, a widespread scourge in his day. I have never felt closer to the excitement a scientist must experience as discovery begins to unfold.

I think of discovery in science as a flash of insight—coming often after years of effort and thought, but coming in any case as a moment of intuitive understanding. (Discovery in my own field of law is more a process of accretion, like the growth of barnacles.) But the years of effort and thought are a necessary foundation. Paul Ehrlich tried hundreds of chemical compounds before he found the "magic bullet." As Peter Medawar writes in *The Limits of Science*, "Nearly all successful scientists have emphasized the importance of preparedness of mind, and what I want to emphasize is that this preparedness of mind is worked

for and paid for by a great deal of exertion and reflection. If these exertions lead to a discovery, then I think it would be pejorative to credit such a discovery to luck."

The intersections between rational analysis and intuitive insight are central to the achievements that have advanced civilization. In the arts, the enduring quality of creativity is clear. The great works of music, painting, and literature of the past mean as much to us today as they did to the people of the age in which they were created—and sometimes they mean even more. In the sciences, however, the great creative moments are like signposts. We leave them behind as we advance in knowledge. But without them, we would not be where we are.

The intersections between rational analysis and intuitive insight are central to the achievements that have advanced civilization.

Distinguished Professor of Physics **Roger Newton,** a renowned mathematical physicist, spoke last year to students at Bloomington who had been elected to Phi Beta Kappa. In his address—which appears also as a chapter in his just-published book, *What Makes Nature Tick?*, Roger described from his own perspective the work of scientific discoverers, past and present:

Imagination, passion, and ideas play at least as important a role in the development of science as in any other creative field of human endeavor.

For some of the creators of the scientific edifice, the urge to understand, to decodify the universe around us had an aesthetic motivation, for others it had a mystical, perhaps even a religious component. Their motivation was certainly not primarily to do something useful (medical scientists excepted), and they did not simply collect data and deduce theories from them. . . .

In many instances, both in science and in mathematics, just as it is for artists, the search for beauty and simplicity is one of the driving forces that propels the men and women who produce original and fruitful ideas. There is, however, one essential difference between the aesthetic motivation of an artist and that of a scientist or mathematician: while the artist is subject to no other authority, the scientist has to bow before the final arbiter of "truth" as revealed by experiment or observation. Similarly for a mathematician: no matter how beautiful a purported theorem is, it has to be logically correct in order to be accepted as a theorem. Nevertheless, aesthetics plays an important role both in the initial plausibility of an announced result and in the value it is accorded after its proof has been accepted. . . .

If imagination, disciplined by experimentation, is the indispensable tool of the physicist, the framework within which this imagination operates in most instances is mathematics. . . . Possibly the explanation of the remarkable correlation between the abstract ideas of mathematics and our description of nature is simply the fact that mathematics is no more than a very powerful codification of logical short cuts;

Imagination, passion, and ideas play at least as important a role in the development of science as in any other creative field of human endeavor.

scientists need all the logical thinking-tools available for the formulation of what their imagination tells them to be the nature of the universe, and for drawing as many conclusions from their ideas as possible. . . .

Mathematics serves as an abstract and far-reaching organizing principle, without which our ideas would remain inchoate.

Mathematics then serves as an abstract and far-reaching organizing principle, without which our ideas would remain inchoate. "The mathematics enables us to imagine more," wrote Freeman Dyson, "than we can clearly think."

José Escobar, associate professor of mathematics at IU Bloomington, epitomizes in his own work Roger Newton's description of the imaginative power of mathematics. José was honored last year with the prestigious Presidential Faculty Fellowship, a national award that recognizes university scientists and engineers who are outstanding in both research and teaching. In a recent conversation he talked about his research discovery and his approach to teaching.

My current research is on linear and nonlinear partial differential equations in geometry. One of the things I have accomplished is developing the theory for the existence of solutions to partial differential equations that are nonlinear. These equations appear naturally in geometry.

Think for example about the surface of the earth. It is curved—so if you want to go from Indianapolis to Seoul, Korea, you cannot go by a straight line. You have to make a curve. When you want to study these curved spaces like the earth, one thing you can do is to deform the shape—make a sphere more ovoid, for example—and see what properties remain the same.

At the beginning, people were skeptical. That problem is too hard, they said, you are not going to solve it.

When you do these deformations, the partial differential equations that I study begin to appear, and I have solved them. No one had done that before. I have been working for years on them. At the beginning, people were skeptical. That problem is too hard, they said, you are not going to solve it. But I kept on working, and little by little I solved the whole set of nonlinear differential equations.

I wasn't aware of it, but the theory for the existence of solutions I developed has applications in other fields. I gave a lecture at a conference recently and another mathematician was there who is probably one of the world's experts in relativity. He told me that my theory is important to his work in studying the structure of black holes. "With your theory," he told me, "now we can understand their structure."

That is one of the reasons I love mathematics. With mathematics you can go from a very specific idea to a great generality. An idea you have that solves a particular problem can be applied to solve a very general problem in several fields—in physics and biology and geology, for example.

It is clear to me that the most challenging aspect of my work is to blend research and teaching. I think this is extremely difficult, because both of them are very time-consuming, and

in both it is difficult to achieve excellence. To teach calculus, for example, when I spend most of my time thinking in terms of very advanced theories, means that I have to try hard to see things the way my students are seeing them.

My main goal as a teacher is to help students develop a self-empowering attitude toward learning mathematics. One of the things I can say for sure is that if I have succeeded in solving anything or achieving anything, it is because I have worked very hard; it doesn't come for free, the knowledge. That idea is something that I would say some of the students are not used to when they come to Bloomington. But they do want to learn, and when they have been with me for several weeks, and have seen the change in themselves, they are happy about it.

I always tell my students that mathematics is not for geniuses. I believe honestly that almost anyone can learn a course of calculus and do it very well.

It is clear to me that the most challenging aspect of my work is to blend research and teaching. I think this is extremely difficult, because both of them are very time-consuming, and in both it is difficult to achieve excellence.

Raima Larter, professor of chemistry in the School of Science, Indiana University–Purdue University Indianapolis, is also a remarkable discoverer, whose work crosses many fields. In her current research she analyzes biochemical systems from the perspective of the new theories of chaos. Recently she described the research discovery that launched her study of chaos.

I was studying a computer simulation of an unusual chemical reaction that occurs in plants. Typically chemical reactions will take a beginning set of chemical substances and convert them smoothly into a final set. But this reaction was different. It would start to move toward completion and then it would go back, and it repeated that back and forth motion over and over.

When I made a computerized mathematical model of the reaction, the model showed a huge array of very complicated patterns. They were beautiful and regular patterns, but I couldn't see at all how they were related to each other. I began staying at the lab until midnight every night, and getting up at six and coming back, trying to figure it out. I was absolutely obsessed because I knew there was something there, but I couldn't see what it was. Finally I took all the graphs and spread them out all over the place. I thought if I could just see all of them at once, somehow the logic of the patterns would hit me.

I was absolutely obsessed because I knew there was something there, but I couldn't see what it was.

I think I was on the verge of giving up when something—I still don't know what—made me remember a research article on mathematics somebody had sent me a couple of years before. I found the article in a drawer, and there in the illustrations were the same patterns that I had been finding—exactly the same. The subject of the article wasn't even similar to what I was working on—but the patterns were the same. And I thought, how amazing.

The mathematician had a formula for putting his patterns in order. I saw I could assign the same kind of formula to mine.

When I did that, everything fell into line and I had the answers to the puzzle of the chemical reaction I had been working on. I was so excited I wanted to tell someone, but it was one o'clock in the morning. At least I resisted calling my students!

This was actually the beginning of my studies of chaos, because it turned out that all of these orderly patterns were just the tip of the iceberg. In between each of the orderly patterns was chaotic behavior. All this has to do with connections and interactions. It may be, in fact, that interactions are the essence of things that are highly organized and complex. And the way one describes these interactions is helped by the new theory called chaos theory.

I've struck up a collaboration with a colleague who has a joint appointment in engineering and medicine. We've begun a discussion series where faculty interested in chaos theory come together from all over the campus, just to talk to each other. He's working on a study of epilepsy that I plan to become involved in. Normal, healthy brain waves are chaotic. But when an epileptic has a seizure, the brain waves become very regular and ordered. I find that amazing, that when our brains are working right, we are in the midst of chaos.

I find that amazing, that when our brains are working right, we are in the midst of chaos.

Indiana University has an extraordinary tradition of research excellence in genetics and molecular biology, going back to the 1940s. **Thomas Blumenthal,** chair and professor of biology and senior fellow of the Institute for Molecular and Cellular Biology, carries on that tradition today. Listen to his description of a research breakthrough in his own work—one that has brought new knowledge about the foundations of life.

The science I work in is biomedicine. In my lab we study the mechanisms involved in the action of genes. Essentially what I am trying to understand is the basics of life. Our society has decided that the way to better health is more knowledge of how life works. And it has been proven over and over again that this kind of basic knowledge we're trying to gain is crucial to understanding disease.

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At the most basic level, all living things are divided into three groups. Two of the groups are bacteria. The third is composed of all other forms of life—plants and animals, from the simplest single-celled organisms all the way up to human beings.

It was discovered a long time ago that the genes in the two groups of bacteria tend to be organized in clusters. The clusters of genes are related by their function and controlled together—like a set of books on the same shelf, all of which have to be read at the same time to accomplish something. It has also been known for a long time that in the third group of life, the plants and animals, genes of related function are not clustered. Instead they are scattered apparently randomly. It's as though you have to pull one book from one shelf, one from another shelf, one from yet another shelf, and somehow open them all at the same time. It makes no sense that things are that way—

but life is in the process of evolving and it often makes no sense.

In my lab we work on a small worm called C. elegans, *which has been intensively studied over the past 20 years by genetic researchers around the world. It's an animal, so it's way up on the chain of life, and its relatives cause a great variety of diseases.*

A couple of years ago we found an interesting thing happening in the way genes are expressed in C. elegans*—something we couldn't explain at all. But one day the thought came to me that in fact we could explain it if, in* C. elegans, *genes of related function were arranged in clusters, just as they are in bacteria. But this idea was completely unheard of. Higher organisms had been studied in great detail over two decades and there was almost no possibility that something like that could have remained undiscovered. I thought, no, this is absurd, this couldn't be true.*

No one expected this similarity would turn up among the three groups of living things.

On the other hand, I couldn't come up with any other explanation. So eventually a team in my lab began working on this idea—or rather, trying to disprove it, because I really believed that it couldn't be true. But we worked on it and worked on it, and new examples of the clusters began turning up, not just here but in other labs. By now there is no question whatsoever that this phenomenon is correct, and we published the results earlier this year.

So now we know that a higher organism, an animal, arranges its genes in units that are essentially equivalent to the clusters of genes in bacteria. No one expected that. No one expected this similarity would turn up among the three groups of living things.

This is a peak experience in the life of a scientist—to discover something that was not known before. It's that moment when you know something is true. It's the "aha!" experience of thinking of it in the first place, and then the grinding years of work that result in your knowing for certain that it's true. It's incredibly exciting, and it's what we must often endure years of frustration for.

Because you're exploring the unknown in science—that's the very nature of the work—most of what you do fails. So you have to be emotionally prepared to live a life of frequent failure, in order to be able to make that contribution in the end.

Let me be clear about those years of frustration. Because you're exploring the unknown in science—that's the very nature of the work—most of what you do fails. So you have to be emotionally prepared to live a life of frequent failure, in order to be able to make that contribution in the end.

This is something I try to communicate to young scientists coming in, that you have to be the kind of person who can stand a significant amount of failure in your life, hoping that in the end you're going to be able to work out success. In the process, you mustn't be too attached to your own deductions. You have to remain willing, perfectly willing, to prove yourself wrong.

SCIENCE AND SOCIETY

Look around at the room you are in and ask yourself how many of the things in it would have been there in the year you were born. I suspect that if it is like the room where I am now writing, the answer is, not many. Much that we use every day—and take for granted—in our homes and offices would have seemed little short of miraculous just a few decades ago. In the 1940s, for example, the lucky few who had television sets could watch the Roller Derby in black and white. Today, millions enjoy the Super Bowl live by satellite, in color, and with instant replay. Microwave ovens, pocket solar-powered calculators, home computers, and cordless telephones—all virtually unthought of in our grandparents' day—are sold in the store around the corner.

The road from research discovery to practical application is often long and rarely straight.

These benefits for society derive from scientific research. It is not often the case, however, that the derivation is direct, or foreseen by the researchers. Our technological world of today is built on knowledge created as a result of human curiosity—our innate desire to peer into the unknown, to find out how the universe works, to understand why things are as they are.

The road from research discovery to practical application is often long and rarely straight. Years, even decades, may go by before the benefits of new knowledge find their way into our daily lives. But we must take the first steps into the unknown before we can discover where we are really going.

As biologist and author Lewis Thomas reminds us, it took a half century of intense research to discover the causes of infectious disease. Only when this discovery had been achieved could medical science reach the level of understanding necessary to develop penicillin, streptomycin, and other life-saving medicines. "Without that painstaking effort," Thomas writes, "the search for antibiotics would have made no sense at all."

A mere lifetime ago the interior of the atom seemed of purely academic interest.

The exotic research of today, such as the investigation in physics of quarks and antiquarks, may seem remote from pressing social concerns. But 150 years ago the study of electricity was considered an exotic topic. A mere lifetime ago the interior of the atom seemed of purely academic interest. But this academic interest led to new diagnostic technology in medicine, new ways to sterilize food, and new materials for everyday products, including the chips that power home computers—to name just a few of the results that could not have been foreseen by the pioneer researchers in high-energy physics.

We must take care to protect programs and fund research in areas that are not now considered of direct benefit to industry, government, or the general public. Today's abstruse pursuits may become tomorrow's achievements, and their value, once apparent, may be very great indeed.

Stuart Mufson, chair of the Department of Astronomy at Bloomington and an international researcher in astrophysics, spoke to this point in a recent conversation as he described his own work:

What is the function of science in society? That's a question we all have to ask ourselves. Particularly as astronomers, we are asked that kind of question often. I don't usually think, when I get up in the morning and come to work, what am I going to do today that's socially relevant? But I do get asked the question a lot. "What is the benefit of what you do?"

For me personally, I really love what I'm doing. It's the grand hunt. It's the great puzzle of how the universe works. There's tremendous satisfaction when you come to understand even a little piece of that puzzle that you may have worked at for a very long time.

You often hear people say that if it weren't for research science, there would be no technological advances. I think that is a little too simplistic. Research and technology are really symbiotic: It's hard to see how technology could advance without science, or science without technology. We take the cutting edge of technology and use it to go forward the next step in understanding. Then that step often means somebody making a discovery that leads to still more advanced technology that society can use in other ways.

The teaching of science is also extremely important. Science should be taught continuously in the schools, right up through college. If you live in this technological society we're making, you need to understand something about science and technology. They should not seem totally inaccessible. They should not be black magic. Many of the students in our large introductory classes think that science is way beyond them. We need to break down those barriers, and the earlier we start in the schools, the better. So from my perspective as a scientist, there is the function of science in society, and there is also the function of scientists teaching science. We have to concentrate on both.

From my perspective as a scientist, there is the function of science in society, and there is also the function of scientists teaching science. We have to concentrate on both.

My work is in high-energy astrophysics. The focus of my research right now, and that of several of my students, is a joint Italian-American experiment to study the evidence of very high-energy interactions that occur at the centers of stars. One of the things we are looking for is a type of particle—called a neutrino—that is produced by these interactions. Neutrinos are very hard to capture because their interaction with matter is minimal. To capture them at all you need a giant detector like the one I work at in Italy—almost as long as a football field and 12 or 15 yards high.

These particles are extremely energetic and tell us something about the unimaginable sources of energy that power the stars. Sometimes, at the end of their lives, stars suffer a catastrophic explosion known as a supernova explosion. Those explosions

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are perhaps the most spectacular events that occur in the cosmos. When stars explode they deliver as much energy in a few seconds as an entire galaxy of billions and billions of stars gives off in those same few seconds. Whenever that energy is produced, neutrinos are produced. If you can capture them they can give you a glimpse of the processes that produce the energy.

Neutrinos may also help us to find answers to a long-standing problem in astrophysics—the dark matter of the universe. At least 90 percent of the universe cannot be accounted for. It must be there, because we can detect the gravitational effects. But we can't see it. One of the possible ways we might be able to see this dark matter is to capture the debris that results when dark matter particles, whatever they might be, collide with other dark matter particles. Many think that this debris will contain energetic neutrinos.

To find answers to such extraordinarily difficult questions we have to push technology to the absolute limits. And by pushing in that way, new discoveries are made, and new technology comes of them.

To find answers to such extraordinarily difficult questions we have to push technology to the absolute limits. And by pushing in that way, new discoveries are made, and new technology comes of them. I can't swear that what I do will directly lead to benefits of this kind, but I think it will—not through me personally, but through the kinds of work that I do and other astronomers do.

As Stuart looks out from the earth in his research, IUB Associate Professor of Geological Sciences **James Brophy** looks down into it to study the origins of volcanic eruptions. Among his many activities, Jim teaches at Indiana University's internationally renowned intensive undergraduate summer program for geology majors. The six-week program takes place at Indiana University's Geologic Field Station in Montana. My wife, Ellen, and I spent a wonderful weekend at the Field Station two summers ago and we envy the students who have the opportunity of a superb learning experience in a truly magnificent landscape.

Listen now to Jim's description of his work in research and teaching:

Most people have seen films or pictures of a Hawaiian volcano in action—a beautiful burning fountain that really is not as dangerous and explosive as it looks. The eruption of Mount Vesuvius, on the other hand, that destroyed the ancient city of Pompeii in A.D. 79, was of a different kind, far more devastating. The whole mountain blew up. Similar devastation happened in another infamous eruption, in 1902, when the volcano Mount Pelée in the West Indies obliterated the town of St. Pierre and killed 30,000 people.

The controlling difference between relatively quiet eruptions that have taken place in Hawaii, for example, and extremely violent eruptions—such as at Mount St. Helens—is the type of magma, the molten rock beneath the volcano.

The controlling difference between relatively quiet eruptions that have taken place in Hawaii, for example, and extremely violent eruptions—such as at Mount St. Helens—is the type of magma, the molten rock beneath the volcano. Beneath Hawaiian volcanoes you tend to have a very fluid, watery magma that can erupt pretty easily. Beneath Mount Vesuvius,

Mount Pelée, and Mount St. Helens, you had a very sticky, viscous magma. When that erupts, it erupts explosively and can do tremendous damage.

I study the origin and formation of the molten rock beneath volcanoes. My main interest is trying to understand how the sticky type of magma is generated from the very fluid type. It's the fluid type that exists deep within the earth, so there must be something that goes on as the magma rises into the holding chambers under the volcano—something that happens to produce the sticky and much more dangerous type of magma.

There is certainly a component of my research that is esoteric and of simple academic interest: How does one kind of magma change into the other? But there are also practical implications. The process I study not only produces different types of magmas, it also concentrates ore deposits of metals such as copper, zinc, gold, and silver. The sorts of things I look at can help in exploration for these ore deposits.

Also, slightly more distant, is the question of volcanic prediction. In the past decade we have had several volcanic disasters that could have been lessened by better prediction of a pending eruption. Obviously we can't stop a volcano from erupting, but if we can get a handle on what types of signals to look for to determine when it's likely to erupt and with what force, then we can do a better job of evacuating the danger zone.

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For example, we now know that when one of the holding chambers beneath a volcano has sticky magma in it and is goosed from beneath, so to speak, by fluid magma traveling upwards from deep within the earth, that is what triggers an eruption. There are a lot of people working on this same problem. We have been able to work out a general model of how magma changes from one type to another, and how this correlates with volcanic eruptions. We have even had some success in trying to put actual time constraints on the process.

For me there is no more rewarding result than to see the effect of your work on an individual, and to watch that individual grow.

But my life here isn't just research. I view my work as a combination of teaching and research, and the two intertwine with one another. I get tremendous personal satisfaction out of teaching. There is satisfaction, of course, in seeing that your work has benefits for society, but for me there is no more rewarding result than to see the effect of your work on an individual, and to watch that individual grow.

The IU School of Public and Environmental Affairs—with courses on all eight IU campuses—is a national model for research and teaching directed specifically toward major concerns of society, in Indiana and beyond. Assistant Professor of Public and Environmental Affairs **Diane Henshel,** who teaches at Bloomington, epitomizes the goals of SPEA in her research on toxic pollutants:

I am a neurobiologist by training. I do developmental research so I look at the development of the organism as a whole—but

I focus most closely on the brain and other aspects of the nervous system as they change during the growth of an animal embryo.

My research is specifically on how pollutants affect the developing organism. Right now I am focusing on dioxins and related chemicals, which include PCBs. Dioxins are common contaminants in a number of useful chemicals, including some herbicides—and I should say chlorinated dioxins because it is the chlorinated dioxins that are the problem. They are a type of chemical that can bind to a chemical receptor inside living cells, and from there move to the nucleus and affect genomic activity.

My research is specifically on how pollutants affect the developing organism.

What I try to do is look throughout the process of development, hoping that I will eventually be able to see all or most of the different points at which the pollutants are making changes. Genetic control of development is both time-sensitive and environment-sensitive. By "environment" I mean chemicals that the cell is exposed to at a particular time. If developmentally related genes are turned on too early or too late, you might get abnormal growth of the organs developing at that time.

If, for example, for the nervous system to develop normally it needs to be exposed at a certain point to a chemical produced within the embryo—but a dioxin is blocking the production or action of that chemical—then you are going to miss that critical time and the nervous system will develop abnormally. What I am trying to find out is where are the time-critical points, and what is dioxin doing, or dioxin and PCBs, at those critical points to induce abnormalities.

I am very much interested in how my work can be used and applied. In looking at the effect of pollutants on development, I am trying to figure out how that knowledge can be used to assess environmental damage—particularly damage to wildlife.

One of the major concerns regarding dioxins right now is the fact that they seem to affect the immune system—and this happens at much lower levels of exposure than are associated with increased cancer risk.

Also, I would like to see improvements in how risk assessments are done in this country. Risk assessments traditionally have been done using cancer as the endpoint. But there is a growing recognition that cancer is not the best endpoint to consider, and certainly not the only one that should be considered. One of the major concerns regarding dioxins right now is the fact that they seem to affect the immune system—and this happens at much lower levels of exposure than are associated with increased cancer risk.

Trying to prove the effect of a toxin, especially an environmental toxin, can be very difficult. For one thing, it's hard to do a lifetime study on humans—and a controlled lifetime study at that. We know to control for some things, such as smoking and diabetes, but how many things are there that we don't know to control for? We just don't know enough at this time—which is one of the reasons science is so interesting.

I am an idealist in science. I would like to see everybody working together and helping each other. In order to do that you have to be able to step back and look at your work, and other people's work, from a broader perspective. That's the first and most important thing that I want my students to achieve. In my classes I try to have the students learn how to read the literature in the field, to understand the point of view of the writer. And I want them to look with an eye that sees not just what is there, and what has been done, but what is the critical point of information that now needs to be addressed, that could solve the next question.

The Research University

The National Science Foundation has compiled a list of 85 major advances over the past two decades in mathematics, chemistry, astronomy, and earth sciences. The NSF determined that the work of university scientists was responsible for more than 60 of those advances.

Universities have a key responsibility to nurture the independent thinking and the readiness to challenge assumptions that lead to advances and innovations.

Universities have a key responsibility to nurture the independent thinking and the readiness to challenge assumptions that lead to advances and innovations. The freedom to pursue a problem solely because it seems an important problem—and not because of any certainty that an answer exists, let alone that the answer will be of direct benefit to society—is a vital factor in discovery and new understanding. That freedom is protected in the university environment. Over the years my faculty colleagues, in the sciences and in other fields, have often told me that their greatest achievements came when they were least sure what the outcome of their work might be.

There is no question in my mind that this commitment to the process of knowledge, rather than its products, brings an intellectual excitement to the classroom that is a main ingredient in the quality of education at research universities in general, and IU in particular.

I am proud that we are one of the major research institutions in the country, with facilities that are in many cases unparalleled and faculty whose contributions are at the forefront of knowledge. To give just a few examples, work in the biological sciences, chemistry, and geology at IU in recent years has resulted in advances that include an artificial variant of a compound in the sap of tropical trees, known to be effective against leukemia; development of a potent antibiotic insecticidal agent that is harmless to humans and animals; new heat-resistant and nontoxic polymers for the aerospace and commercial air industries; an electrical method that greatly reduces the sulfur content of coal; and the discovery of a

bacterium that may provide a way to help crop plants manufacture their own fertilizer.

The history of ideas is far from orderly. Sometimes pieces of a puzzle must come together from many different fields—and perhaps from knowledge long ago acquired but only belatedly understood—so that at last a dramatic new picture can emerge. The increasingly interdisciplinary nature of research means that there is a greater role for collaboration in science than ever before. The benefits are clear in just two examples: the insights that psychological studies on speaking and understanding language bring to the development of computers that can speak and understand, and the way that research in our chemistry department on the mechanism that activates human genes applies directly to work in our medical school on genetic causes of cancer.

The Department of Chemistry at Bloomington produces more baccalaureate graduates in chemistry than any other chemistry department in the country.

The Department of Chemistry at Bloomington produces more baccalaureate graduates in chemistry than any other chemistry department in the country. It also ranks among the top departments in the nation in external funding for research—an index of the quality and importance of IU research in chemistry. Among the illustrious scientists on the faculty is Distinguished Professor of Chemistry **Gary Hieftje.** Over the past decade, Gary has received virtually every major national honor in his field, including three of the American Chemical Society's top awards. As just one example of his many achievements, he has developed an innovative fiber-optic sensor that allows instantaneous chemical analysis of a product without interrupting the production process—a device that is now used by industrial corporations in Indiana and elsewhere. His research group holds 10 patents. Here Gary gives his own views on teaching and research.

The most rewarding part of my job, for me, is training students. And those are students at all levels. I have had high school students in my laboratory. I have had a lot of undergraduates. I have graduate students, of course, and postdoctoral students, and visiting scientists. I derive the greatest pleasure from seeing people who have worked in my group go out and do well—in teaching, or in industrial research, or in founding their own companies, as several have done over the years.

The unique characteristic of university research—as opposed to research in national or industrial laboratories—is that we train people. That is the main mission of our operation.

I personally view this whole business of research versus teaching as a red herring. The main product of our operation here in the university is the students, the people who sit in the classrooms and work in the laboratories. The classroom teaching instructs them in the rudiments of what they must learn, but the research laboratory is where they really learn how to do science. Viewing things in this way puts a different spin on the kind of role the university should play in the whole scheme of science. The unique characteristic of university research—as opposed to research in national or industrial laboratories—is that we train people. That is the main mission of our operation.

There are several levels of training. Students in an undergraduate classroom have to be taught how to answer questions, so that if someone poses them a question they have a good chance of coming up with the right answer. Then there is the next level of training, when they start deciding which of the questions are most important to be answered—so that they don't spend all their time answering questions that are unimportant. Then the third level of training, which takes place in the research laboratory, is when they start asking their own questions, questions that no one else has asked them.

The final step, which occurs in some people very early, and in some unfortunately not at all, is when people become innovative. I have thought long and hard about how to teach people to become innovative, and I don't know how to do it. What I do know is that innovation can be fostered. It requires an atmosphere that provides a lot of freedom—especially freedom to make mistakes. Innovation allows people to make the leap in faith to a new area, to find connections between things that have no apparent connection. But that leap is possible only with a very broad training and in an environment that helps people to think about new things without fear of failure.

I have thought long and hard about how to teach people to become innovative, and I don't know how to do it. What I do know is that innovation can be fostered.

I think we do an excellent job here at IU and at most American universities in training students to become scientists. But we need to do more in educating the broad range of students who will also have a stake in the scientific enterprise, but are not planning on a scientific career. That is one of the reasons I support so strongly our chemistry courses for nonmajors. I have taught those courses myself and I find them challenging and enjoyable.

In a university we are free to answer questions that no one else has asked yet. No one gives us a set of questions and tells us to find the answers to them. We are supposed to come up with our own questions. In seeking the answers we often arrive at very interesting ideas and concepts. So I think one of the important roles the research university plays in science, and in science education, is to provide the freedom to ask difficult questions.

In a university we are free to answer questions that no one else has asked yet.

Working in our multicampus research university has special benefits for **Joan Esterline Lafuze,** associate professor of biology at Indiana University East and research associate in pediatrics at the IU School of Medicine in Indianapolis. In turn, Joan benefits the University, her students at IUE, and the progress of knowledge about childhood leukemia, through her unusual long-distance combination of teaching and basic research in microbiology.

I teach full time at IU East. The way it has worked out so far, all of my classes have been on two days, but I'm usually there three days and part of a fourth. I come over to the lab at the Medical Center many evenings, then one full day and part of a second day, and I'm usually here on the weekends. So it really is two full-time jobs.

After college I went to work at Methodist Hospital as a lab technician. I went back to graduate school late, as many people are doing now. I wanted to teach—that was my primary draw for going back to school. But I had also learned how important hands-on training and research are. It's hard to stay alive and keep up as a teacher in science unless you're involved, unless you're doing active research. Now, because of my research, when something comes up in a textbook that is more recent than when I went to school, I'm not a stranger to it.

It's hard to stay alive and keep up as a teacher in science unless you're involved, unless you're doing active research.

Teaching and research are so integrated that I really can't picture doing one without the other. I've learned so much from my students. Sometimes a student will ask a question in such a way that it reveals a truth I hadn't even considered before. And that is really important, because science is more about asking questions than it is about finding answers. Often what you think is an answer is really the start of a new question.

In my research group we use the techniques of molecular biology to study T-cell acute lymphoblastic leukemia. This kind of leukemia primarily affects children, and just a few years ago it meant almost certain death. Today the survival rate is much better—about 60 percent—but some of the treatments involve a lot of risk for the patient. We hope that in looking at the genetics of this disease we can find critical sequences, unique sequences that only children with T-cell leukemia have. Specifically, we're looking at the messenger RNA. Our goal is to subtract out the RNA in such a way that we can find what is unique to the child with leukemia.

We take healthy, blood-bank blood and separate the T-cells from it. Then we take the T-cells from a child with leukemia and react the two sets of T-cells—using these magical molecular methods—so that each nucleic acid message has a partner except those leukemic messages that are different. The messages that are different don't have anything to join with, so they hook onto our vector. This process isolates these messages that are different, so that we can then put them in plasmids, for instance, and study them.

Theoretically, after you have subtracted everything else out, what you should be left with is the malignant message itself. So there must be an answer. But getting the process to work is really difficult.

Ultimately you hope you can discover what genetic factor is unique to this malignancy, and then use that knowledge to block the malignancy within the cell itself.

Ultimately you hope you can discover what genetic factor is unique to this malignancy, and then use that knowledge to block the malignancy within the cell itself. Then you might have a more effective treatment for the disease, one that would be less harmful to the patient.

Assistant Professor of Computer Science **Gregory Rawlins** is an associate faculty member in the multidisciplinary Cognitive Science Program at IU Bloomington. Gregory exemplifies in his work on robotics and artificial intelligence the kind of imaginative leap forward from which discoveries come:

So many of the things we do every day seem totally trivial tasks for a human being—like carrying a glass of water across a room. You only realize how difficult that is when you try to make a machine do it. Just bringing me a glass of water would be a big deal for a robot. How does it manage to keep the liquid level in the glass? How does it do that and at the same time navigate through a room? How does it recognize an obstacle when it comes to one?

Let's suppose the robot has cameras to "see" with. It will also need some way to process the information about what it is seeing. It's going to see a lot of designs, shapes, and edges—but what are they? How does it recognize if an edge is the edge of a carpet, or a wall, or the edge of a couch that is standing in the way? How does it recognize the couch as an obstacle? If I program my robot with a map of the room, it could maneuver without having to figure out about the couch. But then if I move the couch it's going to bump into it. So I have to program the robot to recognize things—and to recognize new things, because things change.

Eventually we'd like to send robots to the bottom of the sea, or to Mars or Jupiter—to explore places where it is uncomfortable or impossible for human beings to function.

And what happens if there's an earthquake while the robot is on its way with the glass of water? What does it do? The ceiling has fallen in and I'm hurt. Does it continue to bring me the water? We wouldn't want a robot that would do that. We would want a robot that would come and help us. We would want it to be adaptable.

Eventually we'd like to send robots to the bottom of the sea, or to Mars or Jupiter—to explore places where it is uncomfortable or impossible for human beings to function. One solution to the problem of control might be to use a virtual reality system—they already exist—to connect the robot with a control station. Say you have a robot two miles down in the Atlantic, and you're on Cape Cod. With virtual reality, when you move your hand the robot moves its hand. It's like putting a human being at the bottom of the sea without the human being actually having to go there.

A robot that is tied to the way we design computers today would take too long to figure out what to do in complex situations.

But this would not work for exploring Mars or even the moon because of the time lag. At the speed of light, communication with the moon still takes two or three seconds, and with Mars it's several minutes. If the robot is in a situation where a rock is about to fall on it, it can't wait several minutes for instructions on how to survive. It has to react on its own.

A robot that is tied to the way we design computers today would take too long to figure out what to do in complex situations. So what we really need to do is to give the machine the power to learn. We need to give it that kernel of adaptability that will let it learn and react and deal with unforeseen events—and that is easier said than done.

One of the ways we are trying to understand how to achieve this is with genetic algorithms. That is, we are trying to figure out what factors are really important in the genetic evolution

of living things in their ability to process information. Evolution is a learning strategy in the sense that at the end of a long period of evolutionary time the organisms in a particular niche have become more complex, more capable. They are able to deal with more variables and deal with them quickly and successfully—and that's what we want a robot to be able to do.

Human beings are very good at learning. It's bred into us. In the classroom I teach people ideas, I guide them, I try to help them make better use of their learning abilities, but I don't teach them how to learn, in the most fundamental sense of the word. We don't even know exactly how we learn. So that makes it very challenging when it comes time to teach a robot how to learn.

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In the course of his research on fossil flowers a few years ago, **Gary Dolph,** professor of botany at IU Kokomo, unearthed in a Kentucky claypit the oldest intact seed-bearing flower ever found—a 54-million-year-old discovery. Gary's work on fossil flowers, combined with his research on contemporary plant life and the effects of climate, has implications for oil and gas exploration—but that work is just one of his many research interests. He is the author of close to 100 articles on a broad range of topics. In more than 20 years at IUK, he has been a major force in shaping the campus's programs in biology.

I don't see how my courses could function without my doing basic research and research on teaching. The vast majority of the labs I use I have written and designed myself. They come from areas that I have been interested in and done research in for most of my life.

The vast majority of the labs I use I have written and designed myself. They come from areas that I have been interested in and done research in for most of my life.

I try to have my students learn by doing things that are unique and hands-on. For example, in the freshman nonmajors biology course, we buy fossil fish—a long-standing research interest of mine—that are totally unprepped. I get them from a quarry in Wyoming. For the term project each student takes a fish that is still encased in sediment. With probes and dental picks they expose the entire fish, and then they go to work on identifying it. This project is scientific in nature, but not textbook oriented, not paper oriented, not something where students just copy down ideas from somebody's article. But without my own research interests in fossils, I wouldn't have had been able to develop this lab for my students. You don't find any of this in the lab manuals that publishers sell.

We also do a lab on tree-ring analysis and dating that ties in with work I have done on plants and civilization, and two archaeological digs I worked on in the Southwest. As a result, my students can study things from those digs that probably won't be written about for another 10 years or more, and look at photographs of specimens that are still hidden away in the back rooms of museums.

In a standard year here I teach seven different courses, from the graduate/junior/senior level right down to freshman

nonmajors biology. So I have to be good at a lot of things. And I have always disliked taking somebody's textbook and paraphrasing it. In my own days as a student, I learned from every teacher I had—but I didn't have much respect for the ones who just talked about what the book said. So now, as a teacher, I try to bring my personal experience into the course. But this is something you just cannot do if you are tied to lecturing. If everyone were tied to doing lecture notes, there would be no new ideas anywhere. We would all be writing lecture notes from each other's stale lecture notes.

I have had several undergraduate students who have done basic research with me, and we have published everything they have done. That is one thing I insist on—that if a student wants to work on a research project with me, we will publish the results. I can't see wasting their time, or wasting my time, just doing a glorified lab that we could do in a regular course. So if they want to get into the nitty-gritty, we will get into the nitty-gritty. We will roll up our sleeves, and they will learn a lot. I will learn a lot, too, because they have ideas that are brand new—and that is what makes research fun and exciting.

I have had several undergraduate students who have done basic research with me, and we have published everything they have done.

Learning and Teaching

More than a half century ago, I reportedly returned from kindergarten calling my teacher "mother." Her real name was Mrs. Scattergood. My mother did not like this turn of events, but in later years she claimed she knew from then on that I would become a teacher. I've never been sure why this incident produced her flash of predictive insight, but I am sure that Mrs. Scattergood was the first of a small band of teachers who have had a profound, shaping effect on my life.

On the faculty of Indiana University are many extraordinary teachers who help to shape the lives of our students—women and men for whom teaching is an essential expression of their own love of learning and their dedication to increasing the sum of human knowledge. Great teachers must themselves be great learners, and the quality of their teaching is a function of their own learning. The most important lessons of any course or seminar are not some bundle of facts—usually outdated within a few years—but how to learn.

Great teachers must themselves be great learners, and the quality of their teaching is a function of their own learning.

I know from my own classroom experience that the interaction between research and teaching works two ways. Faculty members bring their learning from the laboratory or the library into the classroom—but there are also many times for me, as for my colleagues at IU and elsewhere, when a student's comment or question opens up a new direction of inquiry, or compels reanalysis in ways that lead to new insights. The energy and stimulation of students enrich the life of the teacher and are one of the great rewards of our profession.

"The house of intellect is by nature averse to orders. One cannot command spirit, cannot command learning, cannot command an atmosphere; but one can contribute to the nurture of all of these."

In the sciences, because of the collaborative environment of most scientific research today, students and teachers have the special benefit of working closely together in teams, where opportunities for personal interaction, mentoring, and inspiration are enhanced.

In his autobiography, *Being Lucky,* Herman B Wells described the responsibilities of the university as a place for learning: "The house of intellect is by nature averse to orders," he wrote. "One cannot command spirit, cannot command learning, cannot command an atmosphere; but one can contribute to the nurture of all of these."

An undergraduate education should contribute to the nurture of our students, providing a climate where they can stretch to the full reach of their abilities, and where they are inspired to define the values and goals that will shape their future.

In that spirit, what follows are the thoughts of two of Indiana University's outstanding teachers and their students: **Catherine Olmer,** professor of physics at IUB, and **Gayle Wozniewski,** a senior majoring in physics and chemistry, who participated in the summer research program Cathy directs; and **Sandra Winicur,** associate professor of biology at IU South Bend, and her former student **Edward Boyts,** who graduated from IUSB in 1983 and received an M.D. from the IU School of Medicine in 1987.

The Cyclotron has a long history of involving undergraduates in research.

Catherine Olmer heads the Summer Undergraduate Program in Nuclear Physics at the Indiana University Cyclotron Facility. The 10-week program, supported by IU and the National Science Foundation, provides intensive hands-on research experiences for outstanding undergraduates in physics from Indiana and beyond. Cathy, who received the Herman Frederic Lieber Award for distinguished teaching in 1991, also heads the new Women in Science and Mathematics project at IU Bloomington, designed to gather information about women faculty and students in the sciences and explore possibilities for mentoring. Here she describes the goals of the Cyclotron's summer program for undergraduates.

We have students working in just about every area of the facility. Some are working on our new ion source that has just been built, or in the radiation therapy area we are developing for treatment of tumors. Others are working with faculty members on new ways of identifying the properties of particles, or developing new detectors. For 10 weeks, they work side by side with professional physicists.

One aspect of the program that we are particularly proud of is that each student has his or her own research project. At the end of the summer we expect there to be a product—a set of calculations, a detector, a design, or a new kind of target that exists because of that student's work.

The Cyclotron has a long history of involving undergraduates in research. It's part of our educational mission, and the

program receives enormous support from the faculty and research scientists here. Each of them works with the students as a mentor. Their time and their effort and their caring are what make the program successful.

Research is one aspect of teaching that I think does not always get recognized as it should. Students may leave a classroom lecture understanding what was talked about, but understanding at that level is very different from having direct personal experience so that you really understand it at the level of your bones. It is only when they get into a lab situation where they are doing experiments themselves that they begin to achieve that deep understanding.

I want students to come out of the program feeling good about themselves, feeling confident about their own potential to do great things, and feeling that we have been here to help them, to encourage them, to provide them with experience. I don't say "with knowledge," because the knowledge they gain we don't hand to them. They gain it themselves.

Gayle Wozniewski, from St. John, Indiana, participated last summer in the undergraduate research program at the Cyclotron Facility. She has also worked on a research project in chemical physics with Romualdo de Souza of the Department of Chemistry. While still in high school, Gayle—who says she has been fascinated by science all her life—took so many college-level courses that she began at IUB as a sophomore, and will graduate this spring.

My love has always been some type of cyclotron physics, and the summer at the IU Cyclotron was great. I have learned so much more than I would from a textbook. You may learn theory from a textbook, but you don't learn how everything is hooked together—what module needs to be plugged into what, how it gets hooked up to the computer to take data. You also don't get the one-on-one interaction with the professor, the advice, the teamwork, the hands-on experience.

I started out doing research a year ago, and I have been working with Dr. de Souza on developing a special kind of particle detector. First I learned all the software so that I could design it myself. I designed the outsides, then last summer was basically dedicated to designing the insides. For a long time the detector was just multiple drawings of each view, and what material it would be made of, and just an image in my mind. To see it actually built is really rewarding.

To detect a particle, you have a projectile and the target, and the projectile comes crashing into the target and forms a large nucleus. But the nucleus is unstable because it's "hot," and so it will deform into a dumbbell. Then that will split, and most of the time what you get are two ends of the dumbbell. But in some cases a third particle will come from the neck of the dumbbell. My—I call it "my"—detector is designed to detect those small third particles.

Students may leave a classroom lecture understanding what was talked about, but understanding at that level is very different from having direct personal experience so that you really understand it at the level of your bones.

You may learn theory from a textbook, but you don't learn how everything is hooked together—what module needs to be plugged into what, how it gets hooked up to the computer to take data. You also don't get the one-on-one interaction with the professor, the advice, the teamwork, the hands-on experience.

I didn't know what I wanted to do with science when I got here. I entertained notions of doing strictly research. But now I have decided that I want to be a professor. I would like to be able to teach and pass on what I have learned to other people and continue those experiences. That is the best part, I think.

Sandra Winicur has taught biology and other premed and health-related courses at IUSB for two decades. During that time she has encouraged and inspired thousands of students and received numerous awards for her teaching. Last spring she was awarded the IUSB Distinguished Teaching Award and the all-University Herman Frederic Lieber Award.

I find there is a somewhat different challenge in teaching science than in teaching the humanities because in the sciences, students come in expecting they are going to learn absolute truths. They tend to think that science is a set of truths about the universe. But the point of view I want them to gain is that science is a system—a system for observing and describing, and a system for discovery.

Lifelong learning is not just a way of amassing knowledge, but a way of incorporating knowledge into one's world view and values.

I include analysis of values in my classes, and try to show how scientific method, technique, and data can be used as a basis for learning to handle ambiguity—so that students learn to question themselves, rather than just sticking with their original assumptions. Lifelong learning is not just a way of amassing knowledge, but a way of incorporating knowledge into one's world view and values.

For me, the most challenging aspect of teaching science is exploring new ways of presenting the material so that it becomes part of the students' outlook. Especially since I deal with so many students who are going into the medical or health-related professions, I find it very important for them to learn not just the facts, but how the facts are arrived at, what the limits of the data are, how new data interact with old. I expect all my students to learn to think in new ways, to understand how exactitude and ambiguity can exist in the same profession, and to appreciate in what very positive ways knowledge is power.

Especially since I deal with so many students who are going into the medical or health-related professions, I find it very important for them to learn not just the facts, but how the facts are arrived at, what the limits of the data are, how new data interact with old.

I am happiest in the classroom and I think the most important differences I have made in this life professionally have been in the classroom.

Edward Boyts is one of Sandra's students for whom she and her colleagues on the faculty at IUSB made a difference. Today Ed is a family physician in New Paris, Indiana, and an assistant clinical professor in the IU medical school's clerkship program in family practice. In a recent conversation he spoke of his IUSB education in science and the values that have shaped his career.

The environment at IUSB is very conducive to going on to graduate or professional school. I was encouraged by every professor I had. They cared about me, and about every student in my group going through the premed program—and every one of us was accepted to medical school that year.

Dr. Winicur was the health professions adviser, so it was her role to help guide me in the right direction. I also took two courses from her. She didn't spoon-feed you—she made you dig for what you needed. You had to have initiative. To excel you had to know not only everything she taught, but more that you found out on your own, and this was very valuable to me later in medical school.

I took the Bachelor of Arts program in biology rather than the Bachelor of Science program because the arts help you to become a more well-rounded individual. Being a physician is the art of medicine, it's not always the science of medicine. Sometimes patients come in, they complain of things, you listen to them and examine them and are gentle with them, and sometimes that's all they need. The art of listening and communicating comes from being a well-rounded individual.

I enjoy the challenge of helping people control their illnesses, if they have a chronic illness, as well as helping to heal them, to make them feel better—and just making friends with these people, building relationships that will last years and years. I take care of the high school football team and volunteer my time in the school for talks on health. This is all part of caring about your community. I enjoy that and it has always been my inspiration. That's why I came back to a small town.

In family practice we spend a lot of hours, and we have to be there to take care of the toughest things. When the specialist sends the patient back to us and says there is nothing more that can be done, we are the ones the patient turns to. We have to deal with the pain, the chronic pain, the dying, the death in the family. I chose this when I chose family practice, and I have never faltered from that choice.

Being a physician is the art of medicine, it's not always the science of medicine.

For the Future

In David Starr Jordan's day a century ago, the profound transitions taking place in the role of higher education opened up the curriculum in new and creative ways and established research as an important activity in universities. In our own time, further dramatic changes, launched in the 1940s, continue to shape our responsibilities in both teaching and research. Those changes are, I believe, the root of the intense scrutiny universities are receiving now.

The GI Bill opened college doors for thousands who would not otherwise have had that opportunity. Since then enrollments have increased sevenfold relative to the population. Overall, for every student in college 50 years ago, 12 are enrolled today, and the increase continues. Education beyond high school is now required for most new jobs, and financial security is increasingly tied to educational attainment.

At the same time, as universities have gained more students to teach, they have also become the primary environment for research. Following a 1945 report, *Science—The Endless Frontier,* by Vannevar Bush, who headed the wartime U.S. Office of Scientific Research and Development, the federal government made the decision to invest in science via universities. Today federal and state governments, along with private industry and foundations, provide billions of dollars each year for university research, fueling advances in a host of fields that benefit society. Federal funding for university research and development in science and engineering is now more than $10 billion annually, double what it was a decade ago. By comparison, federal support for university research in 1956, the earliest year that such records were kept by the National Science Foundation, totaled $176 million ($880 million in today's dollars).

No university these days can be great in teaching unless it is also great in research. In no arena is this more clear than in the sciences, where strengths in teaching and research are central to the university's responsibilities to society.

These expanded demands for teaching and research mean that major universities such as IU are pulled both ways. We must excel in each endeavor—and maintain the most productive balance between them. Fortunately the demands are interactive. No university these days can be great in teaching unless it is also great in research. In no arena is this more clear than in the sciences, where strengths in teaching and research are central to the university's responsibilities to society.

Advanced scientific research is increasingly expensive. It requires instruments of great complexity, precision, and cost, as well as a tremendous investment in library resources to remain current with the explosion of knowledge. The intensified demands on the resources of the federal government and private foundations, coupled with rising costs, mean that their funds will be available to a shrinking number of select universities. Even now, the National Science Foundation is providing larger and larger grants to fewer and fewer universities. The institutions that will succeed will be those with the key combination of top faculty and state-of-the-art facilities. They will be recognized as international centers of research. The rest will fall by the wayside. Indiana University intends to be among the select few.

Indiana University currently ranks 30th among all U.S. universities in the level of federal research funding—up from 40th in 1988.

A major future challenge, therefore, for Indiana University is to increase the combination of public and private support that is vital to research excellence. In the past six years, IU has done especially well. The University's external grants and contracts have increased in that time by $55 million—a growth of nearly 50 percent—and several multimillion-dollar federal research grants have been awarded to IU investigators. In 1992-93, IU received $170 million in support from federal, state, industrial, and foundation sources. Indiana University currently ranks 30th among all U.S. universities in the level of federal research funding—up from 40th in 1988. Among the top 50 research universities, only one institution—University of California, Davis—had a greater leap in rankings in that period.

This support for research at IU provides direct benefits to Hoosier citizens through research-related assistance to Indiana companies, technological development that directly benefits industries in our State, and the creation of new jobs in the economy.

The National Research Council estimates that 45 cents of every dollar in university research funding supports salaries for jobs that would not otherwise exist. A corresponding study by the Association of American Universities (AAU), using information from the U.S. Department of Commerce and in consultation with the National Science Foundation, reports that every $1 million in research funding to universities creates approximately 40 jobs, directly or indirectly, within the larger economy. In the past five years, external grants and contracts awarded to Indiana University have increased at an average rate of close to $13 million per year. By the terms of the AAU study, therefore, this funding has created more than 500 new jobs each year.

The National Research Council estimates that 45 cents of every dollar in university research funding supports salaries for jobs that would not otherwise exist.

Again by the terms of the study, IU's total of $170 million in grants and contracts during fiscal year 1992-93 supports well over 6,000 jobs in the total impact of that funding.

Many of the advantages that IU research contributes to our State are highlighted by our Institute for Molecular and Cellular Biology at IUB, directed by Professor of Biology Rudolf Raff. The Institute, with 40 faculty from the Departments of Biology and Chemistry and the Schools of Medicine and Optometry, exemplifies the ways in which IU research benefits the economy of Indiana.

Each year, the Institute provides assistance and information to about 60 companies. Eleven of those companies are currently involved in collaborative research projects at the Institute. One such project resulted recently in the development—by Institute faculty Stefan Surzycki and Robert Togasaki, and graduate student Masahiko Kitayama—of the BioNeb cell disruption system, which received an "R&D 100" award in 1993. These prestigious awards, listed in *R&D Magazine*, are given annually to the top 100 achievements throughout the world in research and development. The BioNeb cell disruption system, which has many potential uses in medicine, agricultural research, and other fields that employ genetic analysis, is now being manufactured by Glas-Col Apparatus Co. of Terre Haute.

Each year, the Institute for Molecular and Cellular Biology provides assistance and information to about 60 companies.

In another example of assistance, faculty at the Institute helped Endotech, an Indianapolis biotechnology company, prepare a proposal for the development of a cell lining for artificial veins. The proposal received funding from the National Institutes of Health, and as a result, the product was developed and is now being tested clinically.

The Institute for Molecular and Cellular Biology receives $120,000 in research support from the State of Indiana. The Institute leverages that support with $800,000 of industrial

funding and $6.9 million in federal funding. Thus every $1 of State support helps the Institute to bring in an additional $64 in federal and private research support—monies that also create new jobs in Indiana. In addition, IU graduates who have studied at the Institute are highly recruited by industry. For example, 15 percent of research scientists at Boehringer Mannheim of Indianapolis received their training at the Institute. The scope of advantages to our State resulting from the activity of just this one research center is impressive. We are proud of IU's contributions to Indiana that result from scientific research—a foundation to build on for the future.

Teaching in the sciences is a vital element of undergraduate education at IU.

That foundation rests on the bedrock of teaching. Teaching in the sciences is a vital element of undergraduate education at IU. The academic agenda for Indiana University—*Our University in the State: Indiana at Its Best*—developed in 1988 by faculty from all campuses, stresses the importance of science education for undergraduates. "Computing and reasoning quantitatively; understanding the physical world and its relationship to human activities"; and "using concepts from the behavioral and biological sciences to comprehend human relationships and human communities" are three of the nine primary goals of an IU education described in the agenda.

IU students benefit from the University's excellence in the sciences. Many of our programs rank nationally in the top 20 and some are virtually unmatched. On our eight campuses we have more than 100 research centers—in the sciences and other fields—where undergraduates as well as graduate students can work with leading researchers.

A key goal for the future is to increase the opportunities for undergraduates to become involved in research.

A key goal for the future is to increase the opportunities for undergraduates to become involved in research. Students benefit enormously by working closely with professors in a laboratory, participating on research teams, and gaining hands-on experience. They are learning to be future scientists and teachers, as Gayle Wozniewski said so eloquently. Employers value research experience in young people they are considering as new employees; medical and other graduate schools consider undergraduate research experience as a key indicator of a student's qualifications.

We have an excellent base on which to expand undergraduate research programs that already exist, both formally and informally, on every campus. In the chemistry department at Bloomington, for example, the honors brochure underscores that undergraduate research is the heart of the program:

Undergraduate research normally begins during a student's junior year, although it can start as early as the freshman year. Each student works closely with a faculty adviser and his or her research group and is expected to participate in all aspects of the research problem by becoming familiar with the original research literature, participating in the design and evolution of his or her project, and aiding in the interpretation of the

results. Results of the research are submitted as a written Honors thesis prior to graduation.

In a similar vein, the Department of Biology at Bloomington sponsors a summer research program in which undergraduates work with faculty at our other campuses, selecting a research project that particularly interests them and spending the summer at the other campus. The program has provided superb opportunities for scores of students and created lasting mentor relationships. One example is the research experience of IUB biology undergraduate Marissa Ehringer, who spent the summer of 1993 working with microbiologist Gretchen Kirchner, a member of the biology faculty at IU Southeast. In their research project, Gretchen and Marissa devised a simple method for nonradioactive DNA "fingerprinting," part of a larger project to study bacteria that infect the lungs of cystic fibrosis patients. By the end of the summer they had completed a joint research paper and submitted it to a scientific journal.

The Department of Biology at Bloomington sponsors a summer research program in which undergraduates work with faculty at our other campuses, selecting a research project that particularly interests them and spending the summer at the other campus.

With outstanding faculty such as Gretchen Kirchner, the biology program at IU Southeast has a remarkable record of student success: In the past six years alone, 100 percent of IUS biology graduates who applied to graduate and professional schools in the sciences—nearly 70 students in all—have been accepted by those schools. The opportunity for undergraduates to participate in research is an important factor in that success.

We are working to encourage more young people to look ahead to careers in the sciences. To mention just a few examples: the Physics and Astronomy Open House, held at Bloomington each fall for high school students from throughout Indiana, provides hands-on experiments using some of IU's advanced scientific equipment, lectures and demonstrations by faculty about their research discoveries, and discussions of career opportunities by executives from industries in the area.

The Science Mobile—a project developed jointly by teachers in northwestern Indiana schools and IUN faculty—brings the excitement of science to elementary schools around the State.

At IU East, Project SCOPE (Science Career OPportunities Encouraged) was launched last summer, in cooperation with Richland Community Schools and Hibbard Middle School, to foster increased interest in science and scientific careers, especially among minority and female students.

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At our Indianapolis campus, outstanding summer programs for high school students are offered by the School of Engineering and Technology and the School of Medicine. And at Indiana University–Purdue University Fort Wayne, IU faculty in the Department of Geosciences work closely with teachers in the Fort Wayne and Allen County schools to bring special programs on earth science to the schools. The department has also been asked by the Allen County Boy Scout Council to establish an Explorer Post at IPFW, a project that is planned for next year.

At Indianapolis, the IUPUI/United Negro College Fund research internship program, now entering its fourth year, brings approximately 30 students from historically black and Hispanic colleges to the campus for a summer of research and study.

America's continued strength in science and technology requires that more minorities and women enter scientific careers, where both have long been underrepresented. I am proud that, in this area too, we have initiatives under way at IU, including the Women in Science and Mathematics project just launched at IUB under the direction of Professor of Physics Catherine Olmer, and programs at Indianapolis—in the School of Education, as well as the School of Science and the School of Engineering and Technology—that are designed specifically to help minority high school students learn about opportunities in undergraduate study and careers in the sciences.

Also at Indianapolis, the IUPUI/United Negro College Fund research internship program, now entering its fourth year, brings approximately 30 students from historically black and Hispanic colleges to the campus for a summer of research and study. A key goal of the program is to introduce these talented minority undergraduates to possibilities for graduate study at IUPUI.

I underscore that first-rate graduate students are essential to IU's excellence in the sciences. These students will be the teachers of the future—throughout our State—as well as a pool of outstanding talent in fie'ds vital to economic growth. In terms of graduate fellowships and assistantships, we have a lot of catching up to do with respect to our peer institutions. We need to increase the competitiveness of our graduate funding so that we can attract the best students. Outstanding graduate students produce excellent research, they provide stimulating instruction—and role models—for undergraduates, and they are important also to our ability to attract and retain outstanding faculty.

Our contributions to the State and nation in the sciences and our international stature as a research and teaching university depend on our superb faculty on all campuses. I think for example of IUB Distinguished Professor of Biology Norman Pace, whose work in genetics and molecular evolution has been recognized by a MERIT Award from the National Institutes of Health that extends support for his research through the year 2003. Norm was elected to the National Academy of Sciences in 1991 and was featured recently in a *Time* cover story on the origins of life.

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Distinguished Professor Ciprian Foias and Professor Roger Temam in mathematics are internationally acclaimed for their pathbreaking work on turbulence, as is Distinguished Professor of Physics Robert Pollock for his expertise in the design and operation of cyclotrons, and Professor of Cognitive Science and of Computer Science Douglas Hofstadter, director of the IU Center for Research on Concepts and Cognition, for his major advances in artificial intelligence.

I think also of Lisa Pratt, associate professor of geological sciences at IUB, whose work on ancient climates sheds light on

the global warming issue; Richard Sheffer, associate professor of biology at IU Northwest, who has gathered at the campus one of the largest tropical plant collections of its kind in the world; Professor of Geology James Farlow, of IPFW, also featured recently in *Time* and a PBS series for his research on dinosaurs; and Gerald Ruth, professor of geography at IU Southeast, whose work in the reclamation of land after strip-mining is a valuable resource for the State of Indiana.

Also at IU Southeast, Assistant Professor of Biology David Winship Taylor, a paleobotanist, has developed a new theory of the origin of angiosperms—work that has practical applications in the coal industry and is supported by the Petroleum Research Fund of the American Chemical Society. All these researchers, and hundreds of their colleagues, enrich the diversity and quality of an IU education.

At IU Southeast, Assistant Professor of Biology David Winship Taylor, a paleobotanist, has developed a new theory of the origin of angiosperms—work that has practical applications in the coal industry and is supported by the Petroleum Research Fund of the American Chemical Society.

Two and a half years ago we created the position of vice president for research and dean of the Graduate School. Fortunately for IU, I was able to convince Professor of Physics **George Walker** to step into those new shoes. This year George is chair-elect of the Council of Graduate Schools, a national organization of more than 400 graduate schools. His many initiatives to enhance our research-related programs include a fund specifically earmarked to support collaborative research and scholarship among faculty on different campuses, a University-wide institute on economic development, a series of centers to make research more readily available to Indiana businesses and government organizations, and steps to strengthen interdisciplinary work among departments and within research centers and institutes. In a recent conversation, George described his own views of Indiana University as the "refuge-hut" for education and exploration in the sciences:

The first mission of the University is teaching—educating the next generation of citizens, the next generation of parents, teachers, scholars, scientists, artists, business managers, leaders in government and every other walk of life. For the teacher, it is exciting and rewarding to interact with students, and I believe this is the reason that many outstanding scientists who could have more resources and a higher salary in industry or national laboratories are attracted instead to universities.

For the teacher, it is exciting and rewarding to interact with students, and I believe this is the reason that many outstanding scientists who could have more resources and a higher salary in industry or national laboratories are attracted instead to universities.

I think we should be very humble about what we think students pick up on, how they may be motivated by researchers who go beyond the specifics of the course syllabus. We don't fully understand what influences students and motivates learning. But there is an intellectual magnetism in people who spend their lives searching for new knowledge, and I think that magnetism comes through in the classroom in ways that are crucial to the learning process.

That is why it is so important for us to continue to be very active in our research and scholarship and to make sure that

people who are involved in research and scholarly activity are in close proximity to students.

We also have a special opportunity to pass on knowledge and to create new knowledge. Universities are the keepers of the understanding of our history, our present, our political system, our culture, our understanding of the physical universe, our understanding of ourselves and our relation to others.

The ways we learn, the ways we remember, the ways we experience will change drastically in the next century. Universities will be at the forefront of those changes and we cannot allow ourselves to become disconnected from society if we expect to play our proper role. That is why I see it as a good thing that we have to be more responsible now. It keeps that disconnect from happening. We have to provide the services that benefit society. If we do that, society will treat us as a valuable resource.

The ways we learn, the ways we remember, the ways we experience will change drastically in the next century. Universities will be at the forefront of those changes and we cannot allow ourselves to become disconnected from society if we expect to play our proper role.

The kinds of questions that will be most likely to have strong societal support in the future will be more holistic and global questions than we have attacked in the past. It will also become more evident that state-of-the-art research will require team effort and interdisciplinary work if we are to make meaningful progress on those questions. The University will need to be much more flexible than it has in recent history in breaking down the barriers among departments and disciplines.

Multidisciplinary centers and institutes already provide a framework that complements departments and offers new opportunities. Some of our very best scholars are involved in the interdisciplinary research centers—people who already have outstanding reputations in individual disciplines.

We also have to understand that there need to be short-term inefficiencies in the research system in order to ensure long-term vitality and fertility. While it's true that we will need to have a greater impact on society and will have to look at problems holistically, this does not mean that we should have a federal agency setting priorities for research. Great breakthroughs come from people who don't necessarily hear the same tune that others hear—and those breakthroughs may be stifled if you allow for only one tune. We have to be careful to leave room and opportunity for the person who marches to a much different drummer.

Great breakthroughs come from people who don't necessarily hear the same tune that others hear.

It is very exciting as we look to the contributions that the University can make in helping to reveal new knowledge and in training people who will be involved in that effort. It will be a wonderful opportunity to be one of those people who spend their lives asking essential questions that are associated with one of the great strengths of the human mind, curiosity, and to be able to teach students about things you have recently learned and communicate your passion for new knowledge to them.

A university's work is founded on essential questions about life and the universe. The challenge of discovery and the energy of great teaching spring from the conviction that all knowledge enlarges the world in which we live.

. . . .

I enjoy many moments of great pride in Indiana University. Few match an experience this past October in demonstrating both the interactions of teaching and research and the strengths of One University with Eight Front Doors. During a biennial visit of the State Budget Committee, two undergraduates, Viva Combs and Jennifer Brown, explained their summer research projects, sponsored by the Undergraduate Research Program. Both are students in Bloomington majoring in biology. Viva spent the summer working with biology professor Shree Dhawale at IPFW, while Jennifer learned under the guidance of IUN biology professor Spencer Cortwright. As they spoke about their research work and their plans for the future—Viva to be a doctor and Jennifer to be a science professor—I was struck by what good teachers they had become. They led the Budget Committee members and my IU colleagues through complex analyses; we felt directly their excitement of discovery.

I am proud that Indiana University excels in this realm of learning, and in no arena is that strength more evident than in the sciences.

Professor José Bonner, who directs the biology undergraduate programs at Bloomington, described the importance of research experiences in undergraduate education for students like Viva and Jennifer. "It is not enough just to give students a body of facts," he said. "We need to help them learn how to wrestle with problems on their own, how to think critically and independently. These are abilities students can't gain just by sitting in the classroom." I am proud that Indiana University excels in this realm of learning, and in no arena is that strength more evident than in the sciences

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